BOMBARDIER
Toronto Site
PROPRIETARY INFORMATION

PPS 42.06

PRODUCTION PROCESS STANDARD

CHEMICAL MILLING OF TITANIUM AND TITANIUM ALLOYS

Issue 7
- This standard supersedes PPS 42.06, Issue 6.
- Vertical lines in the left hand margin indicate technical changes over the previous issue.
- Direct PPS related questions to christie.chung@aero.bombardier.com or (416) 375-7641.
- This PPS is effective as of the distribution date.

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TABLE OF CONTENTS

Sections **Page**

Tables

Figures

1 SCOPE

1.1 This Production Process Standard (PPS) specifies the procedure and requirements for chemical milling (chem-milling) of titanium and titanium alloys.

1.1.1 This PPS complements the engineering drawings that specify its use as an authorized instruction. The procedure specified in this PPS shall be followed to ensure compliance with all applicable specifications. In general, if this PPS conflicts with the engineering drawing, follow the engineering drawing. The requirements specified in this PPS are necessary to fulfil the engineering design and reliability objectives.

1.1.2 Refer to PPS 13.26 for the subcontractor provisions applicable to this PPS.

1.1.3 Procedure or requirements specified in a Bombardier BAPS, MPS, LES or P. Spec. do not supersede the procedure or requirements specified in this PPS. Similarly, the procedure and requirements specified in this PPS are not applicable when use of a BAPS, MPS, LES or P. Spec. is specified.

2 HAZARDOUS MATERIALS

2.1 Before receipt at Bombardier Toronto, all materials shall be approved and assigned Material Safety Data Sheet (MSDS) numbers by the Bombardier Toronto Environment, Health and Safety Department. Refer to the manufacturer's MSDS for specific safety data on any of the materials specified in this PPS. If the MSDS is not available, contact the Bombardier Toronto Environment, Health and Safety Department.

3 REFERENCES

3.1 ASTM E1447 - Standard Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity Method.

3.2 BAERD GEN-018 - Engineering Requirements for Laboratories.

3.3 PPS 13.26 - General Subcontractor Provisions.

3.4 PPS 13.39 - Bombardier Toronto Engineering Process Manual.

3.5 PPS 20.03 - Fluorescent Penetrant Inspection.

3.6 PPS 27.04 - Edge Finishing Titanium Alloy Parts.

3.7 PPS 31.09 - Cleaning of Titanium and Titanium Alloys.

3.8 PPS 31.17 - Solvent Usage.

4 MATERIALS, EQUIPMENT AND FACILITIES

4.1 Materials

4.1.1 It is acceptable to use alternate chem-milling materials to those specified herein provided that all the requirements of section 6 are met and the materials have no deleterious effects on the base metals.

4.1.1.1 Maskant that does not degrade base metal, provides complete protection from the etching solution and exhibits good peeling properties.

4.1.1.2 Patch tape, Scotch #472 vinyl tape, Scotch #470 electroplaters tape or polyethylene tape.

4.1.1.3 Protective wrapping paper, neutral Kraft paper.

4.1.1.4 Abrasive paper, 180 - 220 and 400 grits, aluminum oxide.

4.2 Equipment

4.2.1 Chem-milling solution tanks, equipped with temperature indicating, regulating and recording devices capable of controlling the chem-milling solution temperature within ± 5°F and equipped with mechanical or air agitation.

4.2.2 Immersion tanks resistant to the chemicals and to the operating temperatures used as specified in PPS 31.09.

4.2.3 Surface roughness measuring equipment, adjustable to provide a 0.01" cutoff and capable of making surface measurements and measurements 45° into chem-milled fillets.

4.2.4 Part thickness measuring device (e.g., a sharp point, deep throated micrometer).

4.2.5 Lint free cotton gloves (e.g., DSC 422-1).

4.3 Facilities

4.3.1 This PPS has been categorized as a “Controlled Critical Process” according to PPS 13.39 and as such only facilities specifically approved according to PPS 13.39 are authorized to perform chemical milling (chem-milling) of titanium and titanium alloys according to this PPS.

4.3.2 Bombardier subcontractors shall direct requests for approval to Bombardier Aerospace Supplier Quality Management. Bombardier Aerospace facilities shall direct requests for approval to the appropriate internal Quality Manager.

4.3.3 Facility approval shall be based on a facility report, a facility survey and completion of a qualification test program, if required. The facility report shall detail the materials and equipment to be used, the process sequence to be followed and the laboratory facilities used to show compliance with the requirements of this PPS. Any deviation from the procedure or requirements of this PPS shall be detailed in the facility report. Based upon the facility report, Bombardier Toronto Engineering may identify additional qualification and/or process control test requirements. During the facility survey, the facility requesting qualification shall be prepared to demonstrate their capability. Once approved, no changes to subcontractor facilities may be made without prior written approval from Bombardier Aerospace Supplier Quality Management.

4.3.3.1 For approval of subcontractor facilities to perform chemical milling (chem-milling) of titanium and titanium alloys according to this PPS, completion of a test program and submission of suitable test samples representative of production parts is required. Test samples shall meet the requirements specified in section 6.

4.3.3.2 All testing and evaluation specified herein shall only be performed by Bombardier Toronto Materials Laboratory or by laboratories accredited according to BAERD GEN-018.

5 PROCEDURE

5.1 General

5.1.1 For the purposes of this PPS, the term “MRB” (Material Review Board) shall be considered to include Bombardier Aerospace Toronto MRB and Bombardier Aerospace Toronto delegated MRB.

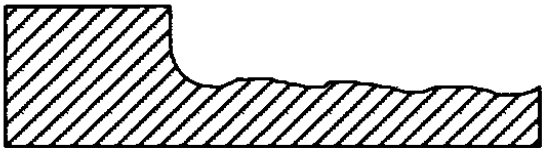
5.1.2 Chem-milling chemically removes material from parts rather than removing material mechanically by machine milling. The amount of metal removed is controlled by the immersion time in the chem-milling solution. Areas where material is not to be removed are protected by a maskant which is impermeable to the chem-milling solution.

5.1.3 Refer to section 5.2 for definitions of terms applicable to the chem-milling process.

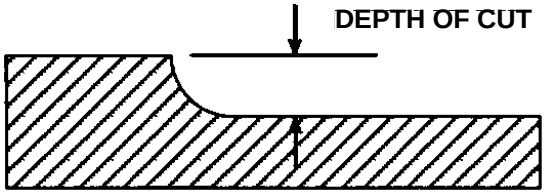
5.2 Terms Applicable to Chem-Milling

5.2.1 *Channelling* - The formation of a groove or channel at the fillet.

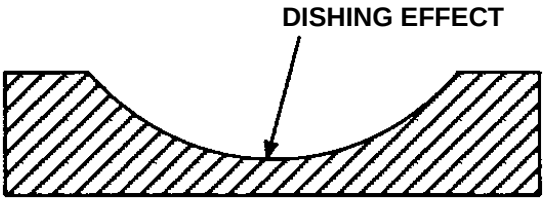
5.2.2 *Channelling, Gas* - The formation of vertical grooves or channels in the etched surface, possibly caused by gas bubbles rising to the etch bath surface.



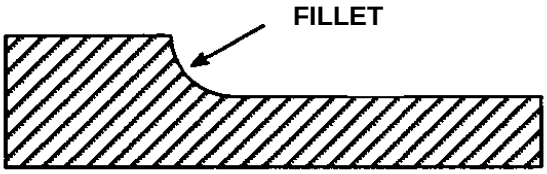
5.2.3 *Cut or Depth of Cut* - The thickness of metal removed, measured vertically from the non-etched part surface to the “nominal” etched surface.



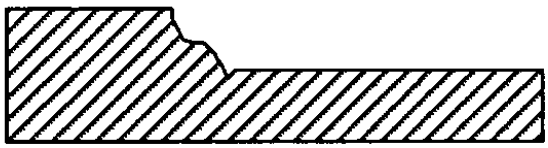
5.2.4 *Dishing* - Central web thinning, resulting from an increasing etch rate from the side to centre, due to improper solution agitation, temperature control or racking.



5.2.5 *Fillet* - The concave or flat shoulder between etched and non-etched surfaces.

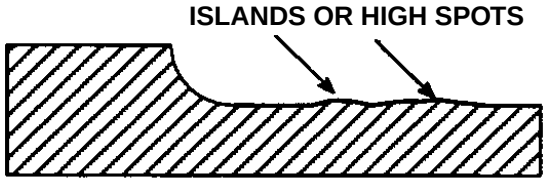


5.2.6 *Fillet Notch* - A notch at the fillet radius bottom, caused by scribing too deeply.

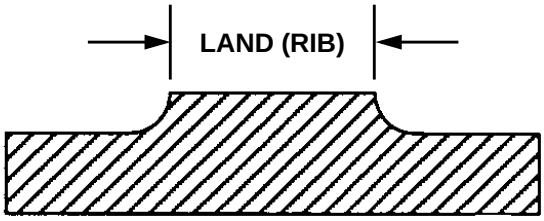


5.2.7 *Gang Milling* - The etching of more than 1 part at once, usually 2 or more parts in 1 sheet, cut apart after chem-milling.

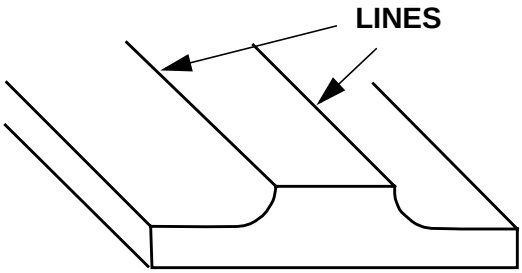
5.2.8 *Islands* - High spots within an etched area, resulting from an uneven etch rate, usually caused by the masking action of dirt or maskant residue left on the surface being etched.



5.2.9 *Land (Rib)* - The raised, non-etched portion of a part.

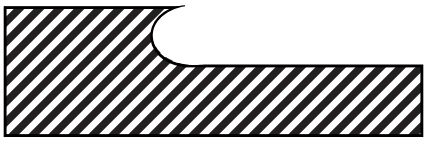


5.2.10 *Line Definition* - The actual quality of the fillet shoulder edge.

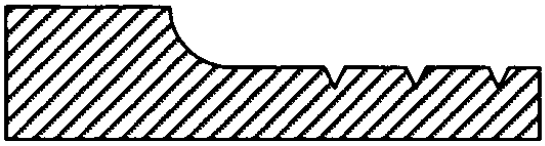


5.2.11 *Monitor Strip* - Test strip of the same alloy and condition as the chem-milled parts. Determine etch rate (material removed/minute/side) by immersing the strip vertically in the etching solution for 30 minutes and dividing the loss in thickness by 60.

5.2.12 *Overhang* - As depicted by the following figure:

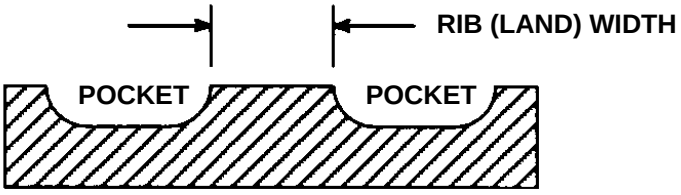


5.2.13 *Pitting* - The formation of pits or depressions in the etched surface.



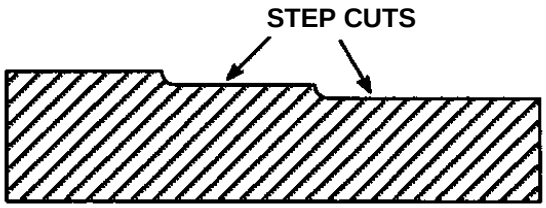
5.2.14 *Pocket* - A cavity formed by chem-milling.

5.2.15 *Rib (Land) Width* - The dimension between pockets, measured from the fillet shoulder edge or line.



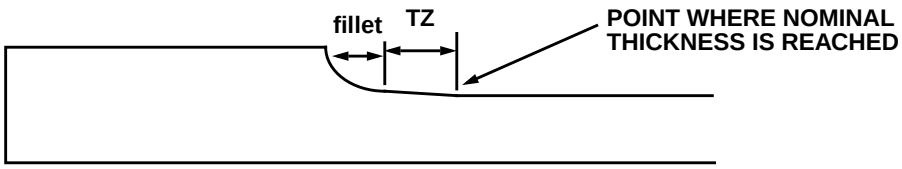
5.2.16 *Ridge* - Formation of a raised ridge at the fillet base.

5.2.17 *Step Cuts* - Multiple cuts of different depths in the same part.



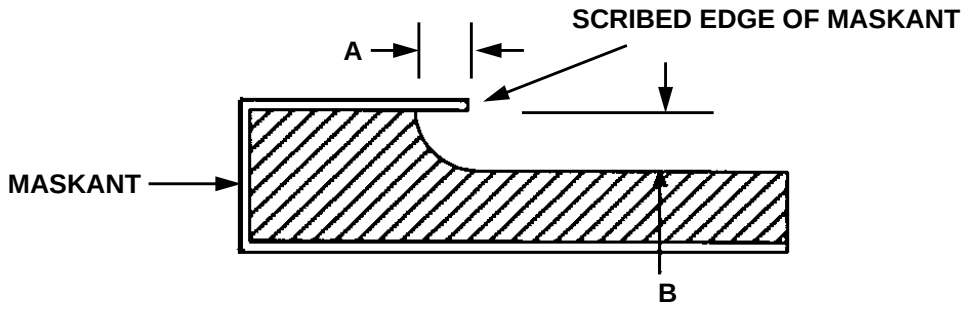
5.2.18 *Taper Milling* - Inducing a taper in a part by immersing in solution and withdrawing it at a continuous controlled slow rate.

5.2.19 *Transition Zone (TZ)* - The distance from the bottom edge of the fillet to the point where the thickness of the chemically milled area becomes constant.



5.2.20 *Undercut* - The amount of material removed by etching underneath the maskant at the scribed edge.

5.2.21 *Undercut Ratio* - The amount of material removed, measured at a point along the original surface from the scribed maskant edge, divided by the depth of cut.



$$\text{UNDERCUT RATIO} = \frac{\text{UNDERCUT (A)}}{\text{DEPTH OF CUT (B)}}$$

5.3 Template Preparation

5.3.1 Allow for the undercut ratio (see paragraph 5.2.21) when preparing templates for chem-milling. The undercut ratio depends on the material type, the depth of cut, the etchant type and the maskant type.

5.3.2 The scribe template dimensions shall provide sufficient maskant to compensate for undercutting on all sides (see Figure 1).

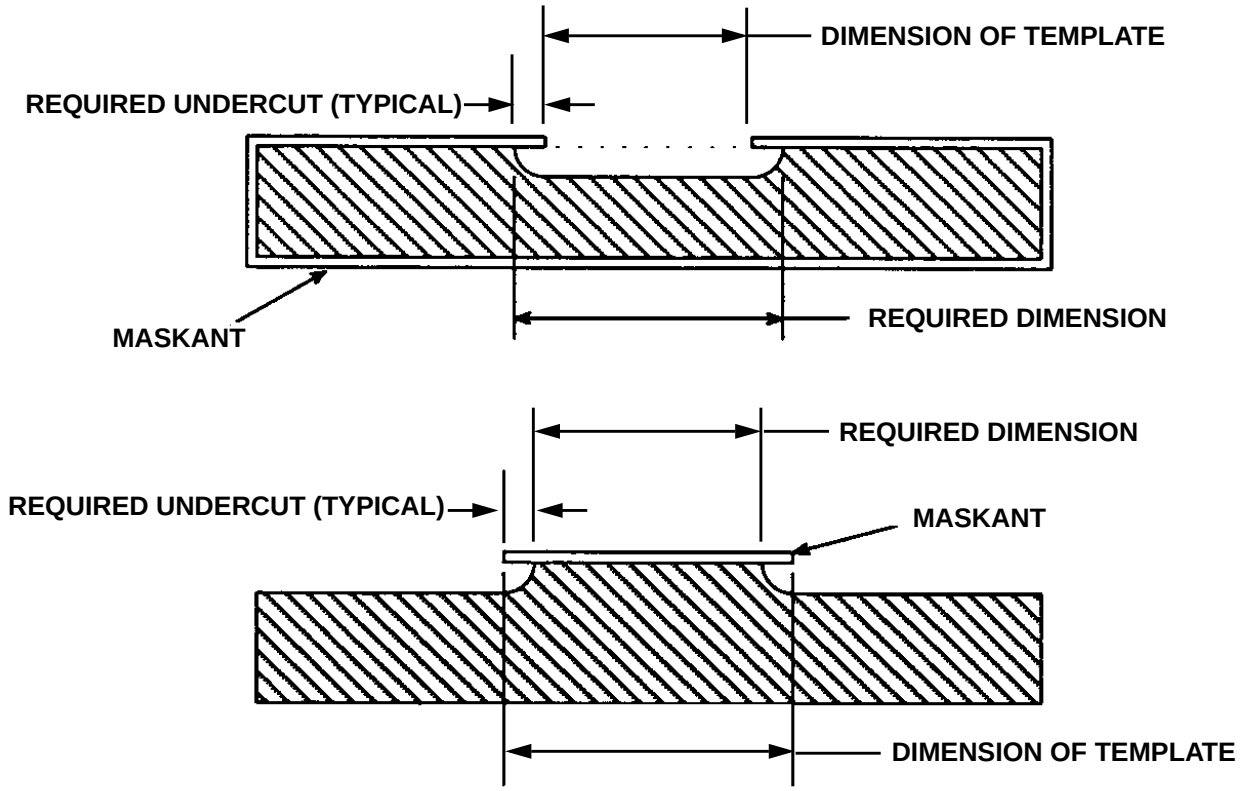


FIGURE 1 - UNDERCUT (TYPICAL)

5.3.3 Radius inside corners of the template to a minimum of 0.125" to permit a continuous scribe line (see Figure 2).

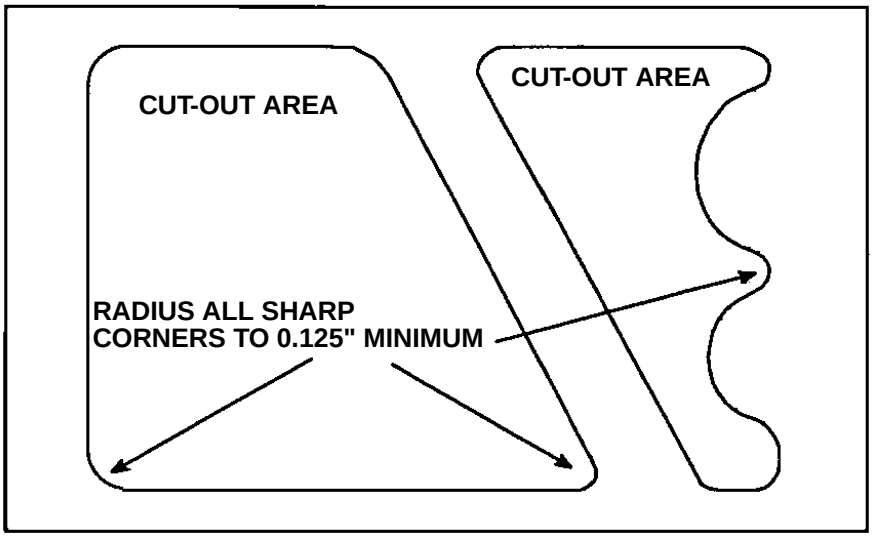


FIGURE 2 - TYPICAL TEMPLATE CORNER RADII

5.4 Pre-Processing Operations

5.4.1 Except as noted in paragraph 5.4.1.1, complete all forming, machining and heat treatment before chem-milling, whenever possible.

5.4.1.1 Perform drilling, other than drilling of tooling holes, after chem-milling.

5.5 Surface Preparation

5.5.1 Except as noted below, ensure surfaces are free of scratches, pits and other irregularities.

5.5.1.1 If possible, re-align the template to avoid a defect in an otherwise acceptable part.

5.5.1.2 If a major defect does not penetrate to the final engineering drawing thickness, paint the defective area with maskant and chem-mill to below the defect depth. Rework the defect flush with the etched surface and complete chem-milling. Contact Liaison Engineering if the defect penetrates to the engineering drawing thickness or beyond.

5.5.1.3 When the defect is less than 0.001" deep, it is acceptable to proceed with the operations outlined herein, provided the prescribed depth of cut is less than 0.075".

5.6 Surface Cleaning

5.6.1 Clean oil, grease, pencil marks, etc. from part surfaces, according to PPS 31.09, to obtain proper maskant adhesion and ensure uniform etching.

5.6.2 Apply maskant within 2 hours of cleaning. Wrap parts in clean, neutral Kraft paper if the delay exceeds 2 hours.

5.6.3 Wear clean cotton gloves when handling cleaned parts.

5.7 Maskant

5.7.1 General

5.7.1.1 The maskant may be applied by any suitable method (i.e., spray, dip, etc.) and shall be such as will provide complete protection from the etching solution and it shall also have good peelability.

5.7.1.2 The maskant shall be completely cured before trimming to the template. Curing time will depend on the type of maskant used and the curing method employed.

5.7.1.3 The final thickness of the applied maskant shall be a minimum of 0.010".

5.7.1.4 After curing, check maskant for defects such as pinholes, blisters, scratches, non-adhering areas, etc. Spark testing to locate defects and pinholes in maskants is acceptable. Repair defects according to section 5.7.2 or section 5.7.3.

5.7.2 Repair of Non-Adhering Areas

5.7.2.1 Repair non-adhering areas as follows:

Step 1. Cut and remove the defective maskant plus a minimum of 1/4 inch around the defect periphery.

Step 2. Solvent clean the base metal according to PPS 31.17.

Step 3. Apply 2 to 4 coats of patching maskant, allowing the solvent to flash off between coats. Allow the final coat to dry for a minimum of 2 hours.

Step 4. If chem-milling for more than 1 hour, apply patch tape (see paragraph 4.1.1.2 for options) over the entire repaired area.

5.7.3 Repair of Pinholes, Blisters and Scratches

5.7.3.1 Repair pinholes, blisters, scratches, etc., as follows:

Step 1. Patch with vinyl tape (see paragraph 4.1.1.2) if the depth of cut is less than 0.100". Patch with electroplaters tape (see paragraph 4.1.1.2) if the depth of cut is 0.100" or greater.

Step 2. Extend the patch a minimum of 1/4 inch around the defect periphery.

Step 3. Use a roller or other suitable tool to press down the tape, being careful to avoid air entrapment.

5.8 Maskant Cutting

5.8.1 Locate the scribe template firmly on the masked part surface.

5.8.2 Using only sufficient pressure to cut the maskant, scribe the maskant to the template outline. Take care to prevent scoring the base metal with the scribing tool.

5.8.3 Carefully peel away unwanted maskant, exposing the surface to be etched. Ensure sharply defined maskant edges that follow the template outline. Remove the template and ensure the maskant is free from the defects specified in paragraph 5.7.1.4.

5.8.4 If milling steps in sequence, it is acceptable to scribe all patterns at once, provided that scribe lines subjected to the etching solution are covered with strip of patch tape (see paragraph 4.1.1.2) and the tape is peeled before removing maskant for each milling step.

5.8.5 Repair damaged, pulled or inaccurate scribe lines before etching.

5.9 Chem-Milling Procedure

5.9.1 Agitate the chem-milling solution before and, if necessary, during chem-milling to ensure uniform etching and to prevent pitting.

5.9.2 Before chem-milling each production batch, use monitor strips (see paragraph 5.2.11) to calculate the solution etch rate or base the etch time on previously processed batch of parts of the same alloy.

5.9.3 Use one part from each batch for process control. Measure the thickness of the sections to be etched and calculate the approximate etch time.

5.9.4 Immerse parts, together with a hydrogen pick-up test sample according to section 6.2.5, for the required etch time, remove and rinse in cold water and measure the dimensions of the process control part. Rotate parts in the vertical plane at 30 minute intervals.

5.9.4.1 On stepped parts, remove the scribed maskant in sequence and rinse in cold water after each milling step. To check the thickness of chem-milled areas, lift or cut a section of maskant to locate a micrometer anvil. Patch the cut section before re-immersing in the etch solution.

5.9.4.2 If required, obtain tapers by immersing parts in the etch solution and withdrawing at a controlled continuous rate. The maximum obtainable taper is approximately 0.100" per foot of length.

5.9.5 If additional etch time is required to achieve required dimensions, measure the initial depth of cut on the process control part, calculate the actual etch rate and adjust the etch time accordingly.

5.9.6 Process the production batch using the parameters established for the process control part.

5.10 Post Chem-Milling Procedure

5.10.1 When the drawing dimensions are obtained on the process control part, remove the maskant coating. Cold water rinse thoroughly and air dry.

5.10.2 Process the remainder of the production batch using the same procedure as that established for the process control part.

5.10.3 Edge corner relieve sharp edges resulting from etching process according to PPS 27.04.

5.10.4 Protect all chem-milled parts for shipment or storage by interleaving and completely wrapping with neutral Kraft paper.

5.11 Rework of Defects

5.11.1 Remove raised areas greater than 0.031" in height using a curved metal scraper or 180 - 220 grit abrasive paper (see Figure 3). Keeping within engineering drawing tolerances, rework local part surfaces that fail to meet surface roughness requirements specified in Table III using abrasive paper (see paragraph 4.1.1.4). Do not use heat generating tools.

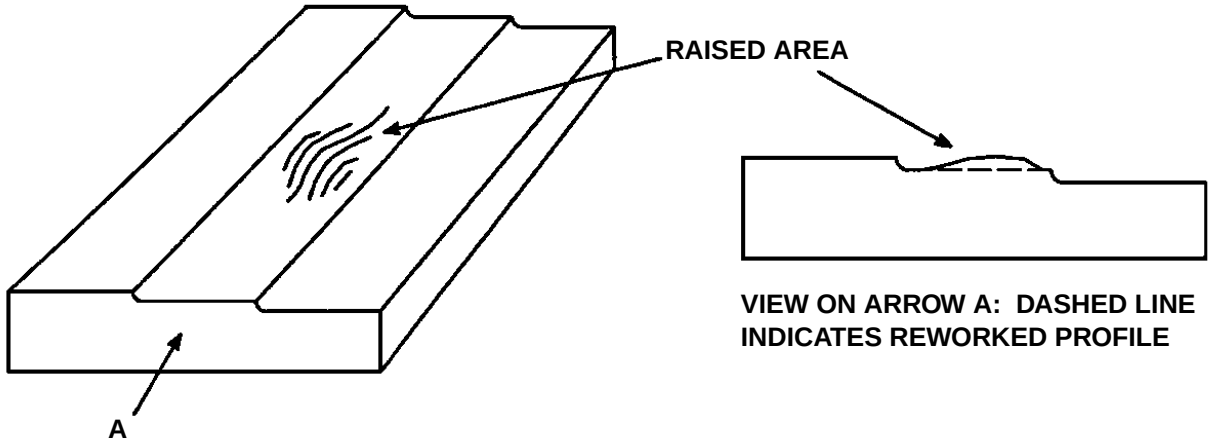


FIGURE 3 - REWORK OF CHEM-MILLED SURFACES (TYPICAL)

5.11.2 Unless otherwise specified on the engineering drawing, obtain the final surface finish in the reworked area using 400 grit abrasive paper.

5.11.3 Remove all sanding residue by solvent cleaning according to PPS 31.17.

6 REQUIREMENTS

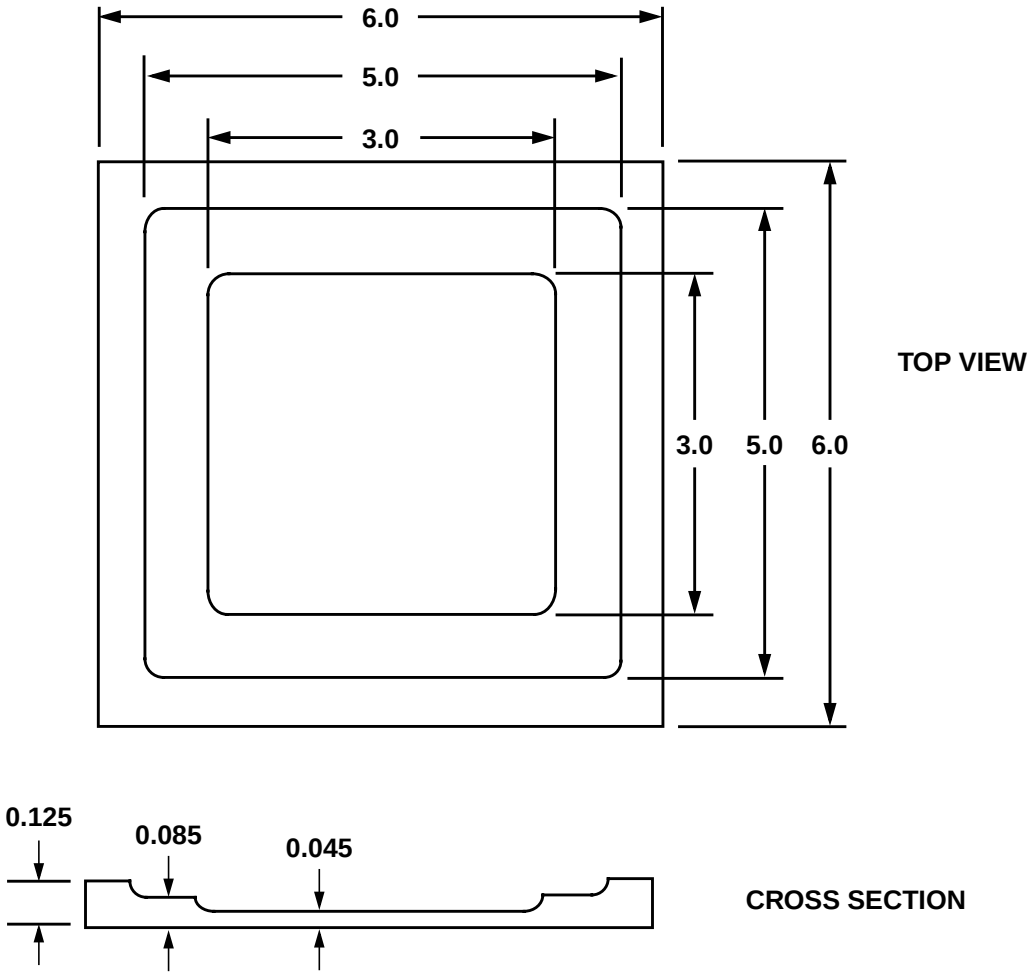
6.1 Process Qualification Tests

6.1.1 In addition to the requirements specified in PPS 13.26 and PPS 13.39, for qualification to produce parts according to this PPS, and periodically from then as requested by Bombardier, chem-mill two SAE AMS-T-9046 6Al-4V test specimens conforming to the dimensions shown in Figure 4. Perform visual, dimensional and metallographic examination on one of the test specimens. The second specimen and the test results of the first specimen shall be submitted to Bombardier Toronto for evaluation and approval. Solution operating parameters shall also be submitted to Bombardier Toronto for review and approval.

6.1.2 Withhold or suspend the qualification process if any chem-milled surfaces show evidence of pitting or intergranular attack greater than the limits specified in Table I, or if the surface roughness requirements of Table III are exceeded after any rework according to section 5.11.

TABLE I - PITTING AND INTERGRANULAR ATTACK LIMITS

MAXIMUM ALLOWABLE PITTING	MAXIMUM INTERGRANULAR ATTACK
0.0005"	0.0002"



NOTE: ALL DIMENSIONS ARE IN INCHES. THE TOLERANCE FOR THE DIMENSIONS SPECIFIED IN THE TOP VIEW IS ACCORDING TO TABLE IV (THE PERMISSIBLE LINE DEVIATION FROM THE IDEAL LINE SPECIFIED IN TABLE IV IS PER EDGE). THE TOLERANCE FOR THE THICKNESS DIMENSIONS SPECIFIED IN THE CROSS SECTIONAL VIEW IS ± 0.003".

FIGURE 4 - QUALIFICATION TEST PANELS

6.2 Production Parts

6.2.1 All testing and evaluation specified herein shall only be performed by Bombardier Toronto Materials Laboratory or by laboratories accredited according to BAERD GEN-018.

6.2.2 Visual Inspection

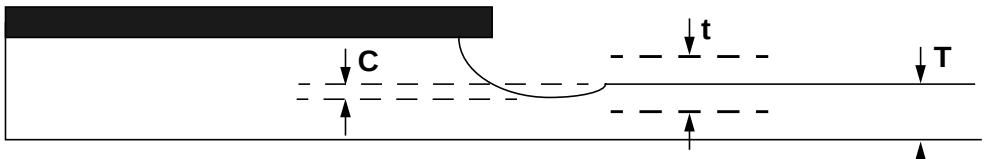
6.2.2.1 Chem-milled surfaces shall be free from roughness, sharp edges, ridging, pitting, distortion, and other evidence of poor workmanship that will degrade the performance of the part. Reject parts showing any of these defects and refer such parts to MRB for disposition.

6.2.3 Dimensional and Surface Roughness Requirements

6.2.3.1 No overhangs are allowed. Channelling is allowed provided that thickness of the part, measured at the bottom of the channel, is within drawing requirements, and that the depth of the channel does not exceed the value listed in Table II.

TABLE II - CHANNELLING DEPTH LIMITS

REMAINING MATERIAL THICKNESS (T)	ALLOWABLE CHANNELLING DEPTH (C)
< 0.040"	0.002"
0.040" - 0.080"	0.003"
> 0.080"	0.004"



Note: t represents the material thickness tolerances.

6.2.3.2 Rework raised areas, that exceed the dimensions specified in Table IV, according to section 5.11. If after any rework, reject parts failing to meet the surface roughness requirements specified in Table III.

TABLE III - MAXIMUM ACCEPTABLE SURFACE ROUGHNESS

FORM	MAXIMUM ACCEPTABLE SURFACE ROUGHNESS (RMS)	
	ACROSS GRAIN	PARALLEL TO GRAIN
Sheet & Plate	63 Micro-inches	
Forgings	100 Micro-inches	

6.2.3.3 Chem-milled lines (rib edges) shall be well-defined and shall not deviate from ideal lines (drawing or loft lines) by more than specified in Table IV and Figure 5.

6.2.3.4 After blending, pits and indentations shall not deviate from the ideal line by more than the amounts specified in Table IV and Figure 5.

TABLE IV - MAXIMUM DEVIATION FROM IDEAL LINE

DEPTH OF CUT	PERMISSIBLE DEVIATION FROM IDEAL LINE (SEE FIGURE 5)		MAXIMUM HEIGHT OF RAISED AREAS (SEE FIGURE 3)
	LINE	INDENTATION	
Up to 0.100"	0.030"	0.040"	0.005"
0.101" - 0.200"		0.065"	
0.201" - 0.300"		0.080"	
0.301" and over		0.080"	

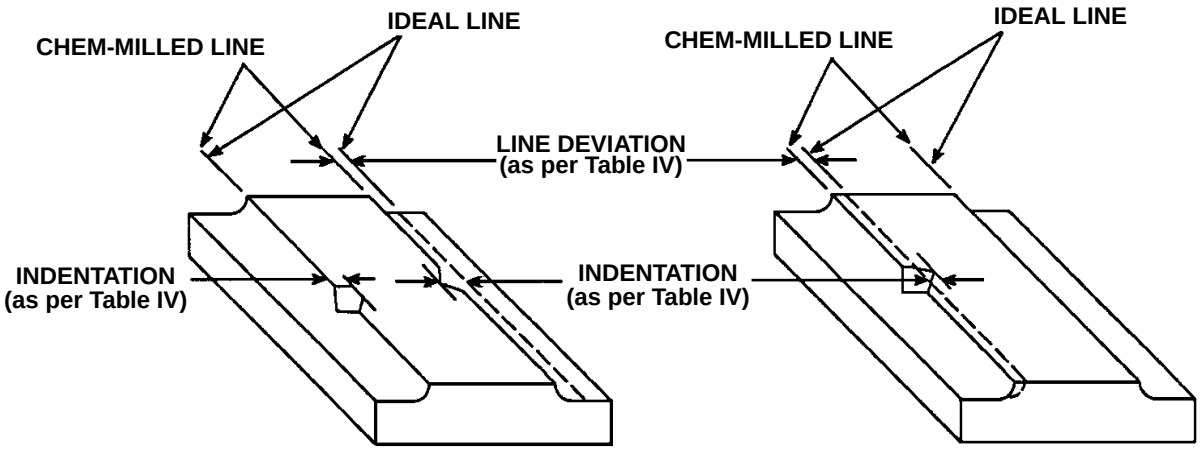


FIGURE 5 - ALLOWABLE DEVIATION FROM IDEAL LINE (TYPICAL)

6.2.3.5 Remaining web thickness shall be as specified on the engineering drawing.

6.2.3.6 Reject parts not meeting the requirements for chem-milled lines, localized pits and indentations and web thickness.

6.2.3.7 Transition zone (see paragraph 5.2.19) length equal to six times the depth of cut or 0.5", whichever is greater, is acceptable. Within this zone, the material thickness may be greater than that specified on the engineering drawing.

6.2.3.8 Inspect one part from each production batch for channelling by measuring, using an adequate thickness measuring device (see paragraph 4.2.4), the thickness of the part directly adjacent to the fillet, and again some distance in from the chem-milled edge. This process will be carried out at 10 different locations along the last cut edge, in the areas most likely to develop channelling (preferably 5 along one axis and 5 in the perpendicular direction). If channelling is determined to exceed the requirements of Table II, reject the part and the batch it represents and refer such parts to MRB for disposition and the chemical milling tanks shall be re-qualified according to section 6.1.

6.2.4 Fluorescent Penetrant Inspection

6.2.4.1 When specified on the engineering drawing or when requested by Bombardier, fluorescent penetrant inspect according to PPS 20.03 before shot peening or shot peen forming.

6.2.5 Hydrogen Absorption Test

6.2.5.1 Once each month, prepare one hydrogen absorption test sample and a control sample with one batch of production parts.

6.2.5.1.1 Process the test sample and the control sample, each approximately 1" X 3", taken from a location adjacent to each other from material of the same alloy and heat treat condition as the production parts, through the same manufacturing operations (i.e., cleaning, etc.) as the production parts except that the control sample shall not be chem-milled.

6.2.5.2 Evaluate the test sample according to ASTM E1447 and the control sample for hydrogen content.

6.2.5.3 Hydrogen absorption of the test sample when compared to the control sample, shall not exceed 25 ppm.

6.2.5.3.1 If hydrogen absorption exceeds 25 ppm, suspend the chem-milling process until the cause of failure has been established and corrective action taken.

6.2.5.3.2 Refer relevant production parts to MRB for disposition.

6.2.6 Process Check

6.2.6.1 Except as noted in paragraph 6.2.7, every month perform metallographic evaluation on one chem-milled SAE AMS-T-9046 6Al-4V test specimen conforming to the dimensions shown in Figure 4 to confirm the chem-milling bath performance (i.e., the requirements of this PPS are met). Pitting and intergranular attack shall not exceed the limit specified in Table I. Submit the test results to Bombardier Toronto and identify and store the tested specimens for a period of one year.

6.2.7 After 12 consecutive successful evaluations, it is acceptable to prepare test specimens for metallographic evaluation every three months instead of every month. However, in the event that pitting or intergranular attack of any of the test specimens exceeds the limits specified in Table I, test specimens shall once again be prepared monthly.

7 SAFETY PRECAUTIONS

7.1 Subcontractors performing work according to this standard shall define safety precautions applicable to the materials and procedure used.

8 PERSONNEL REQUIREMENTS

8.1 This PPS has been categorized as a “Controlled Critical Process” according to PPS 13.39. Refer to PPS 13.39 for personnel requirements.

9 RAW MATERIAL AND FINISHED PARTS PROTECTION

9.1 Keep raw material and finished parts free from moisture, dirt, abrasives, burrs, metal particles, etc. Interleave and completely wrap using neutral Kraft paper.

9.2 If stacking parts, separate them with neutral Kraft paper, corrugated paper, webbing or other suitable material.

9.3 Do not slide or draw material sheets across other surfaces, or across each other. Lift sheets carefully to prevent nicking or scoring surfaces.

9.4 Use corner protectors for transport and storage. Properly support and secure raw material and finished parts during transport and storage. Do not place heavy objects on material or parts.